APPLICATION OF POLARISED LIGHT TO RESOLUTION

BY

DAN M. STUMP

ARMOUR INSTITUTE OF TECHNOLOGY

1921

T
535.8
St 9

Illinois Institute
of Technology
UNIVERSITY LIBRARIES

AT 606
Stump, Dan M.
An application of polarized
light to resolution with

Digitized by the Internet Archive
in 2009 with funding from
CARLI: Consortium of Academic and Research Libraries in Illinois

http://www.archive.org/details/applicationofpol00stum

AN APPLICATION OF POLARIZED LIGHT TO RESOLUTION WITH THE COMPOUND MICROSCOPE

21203
45

A THESIS

PRESENTED BY

DAN M. STUMP

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

MECHANICAL ENGINEER

JUNE 2, 1921

APPROVED:

Geo. F. Gebhardt
Professor of Mechanical Engineering

Dean of Engineering Studies

Dean of Cultural Studies

ILLINOIS INSTITUTE OF TECHNOLOGY
PAUL V. GALVIN LIBRARY
35 WEST 33RD STREET
CHICAGO, IL 60616

TABLE OF CONTENTS.

Foreword 4

Introduction 8

Object 8

Method of Presentation 8

Description of the Diatom Selected 9

Optical System 11

Lamp 11

Light Filter 12

Mount. 12

Setting up Apparatus 13

Image with Narrow Central Beam 13

Image showing Transverse Striae. 14

Supplementary Microscope for adjusting Illumination. 16

Improvement of Image by polarizing Incident Beam . . 16

Image showing Longitudinal Striae. 17

Prism Holder 18

Utilizing Two Beams from One Light Source. 19

Image showing Structure resolved into "Dots" 19

Other Methods of obtaining Separate Beams. 20

Advantages of Described Method of Illumination . . . 21

29849

LIST OF PLATES.

I - General View of Amphipleura Pellucida, x920. . . . page 9a.

II - Apparatus arranged for Visual Work . . . . 11a.

III - Amphipleura Pellucida in Transverse Lines, x4350 . . 13a.

IV - Formation of Diffracted Beam . . . . 14a.

V - Optical System used . . . . 15a.

VI - Amphipleura Pellucida in Longitudinal Lines, x4350 . 16a.

VII - Arrangement of Illuminating Apparatus. . . . . 17a.

VIII- Amphipleura Pellucida in "Dots", x4350 . . . . 18a.

IX - Apparatus arranged for Photographic Work . . . . 19a.

X - Apparatus arranged for Linear Measurment . . . . 20a.

XI - Appearances of Abbe Diffraction Plate, x90 . . . . . . 21a.

XII - Theoretical Apertures required for Resolution. . . . 21b.

FOREWORD

Early in 1917 the author was interested in the resolution of a dry-mounted Fasoldt thirteen band ruling, and had succeeded in faintly resolving the tenth band with 114,000 lines to the inch, by using overhead oblique illumination and an objective of 1.40 Numerical Aperture.

The following brief note was noticed on page 325 of the 1891 edition of Carpenter's The Microscope and its Revelations, "----when resolving striae with oblique light the effect is much strengthened by placing a Nicol analyzing prism over the eyepiece."

Applying this suggestion to the resolution of the Fasoldt ruling, when the prism was revolved to its position of maximum effect, the tenth band was found to be perfectly resolved, each line standing out clearly from the next, and by very careful adjustment, the lines on the eleventh band with 127,000 lines to the inch, were faintly visible.

This result was so very gratifying that experiments were made upon a number of objects having minute periodic structure, and it was found that in all cases where the prism was set so as to pass light vibrating

in a plane parallel to the striae being shown, a clearer image of the striae was formed than when the prism was not used. The best results were usually obtained when the prism was placed in the path of the illuminating beam.

Attempting to explain this phenomenon, it was experimentally found that the diffracted beam was polarized, the light vibrating only in a plane parallel to the rows of markings causing the diffraction. The theory was then advanced that the image of the structure near the eyepiece diaphragm was formed by the interference of the polarized diffracted beam with only that part of the incident beam vibrating in this same plane; and that the remaining components of the incident beam, not entering into the formation of the image of the structure, naturally exerted an obscuring effect on the image, sufficient when this image was faint to entirely obliverate structure otherwise well within the resolving power of the objective.

The function of the polarizing prism then was to remove all of this excess light not entering into the actual formation of the image of the structure, preventing this obscuring effect, and so allowing images

of maximum clearness to be formed.

A careful consideration of this analysis showed that by the use of a single beam of polarized light, the only improvement in any image that could be expected would be a sharpening of the striae in one direction only. No advantage could be gained with an object having structure presenting the appearance of a crossed grating, that is with two or more sets of superimposed parallel markings, since a single prism would at its best improve the definition in one direction only, and would probably destroy the images in the other directions altogether.

Since this type of crossed structure is very common in natural objects, and at the same time presents considerable difficulty in resolution, especially when the interval of the structure approaches the resolving power of the lens in use, it was considered very desirable that a method be found by which the advantages of the single polarized beam could be applied to the resolution of structure of this latter type.

The idea then evolved of illuminating the specimen with as many separate beams as there were structural elements, each beam being polarized in the proper plane to form a clear image of its particular element. The

final image would then be a composite, formed by the blending of several independent images each showing some particular element in the structure. The formation of an image in this manner is merely a modification of methods ordinarily used, the optical principles involved being identical.

In June, 1917, photographs were made of the surface structure of the test diatom Amphipleura pellucida, using two separate beams of oblique light polarized at ninety degrees to each other. These beams were produced from two light sources and directed through two Nicol prisms held in a proper position below the condenser of the microscope.

These photographs were exhibited at a meeting of the State Microscopical Society of Illinois and the author was urged to prepare a description of the method for publication. This work was interrupted by America's participation in the World War, but is now offered in its present form.

It is hoped that some portion of the paper may be found both useful and instructive to workers with the compound microscope.

AN APPLICATION OF POLARIZED LIGHT TO RESOLUTION WITH THE COMPOUND MICROSCOPE.

INTRODUCTION

Most workers with the compound microscope, and especially those who have investigated the resolving power of the instrument, have examined objects, the surfaces of which were found to be covered with rows of markings crossing each other at regular intervals.

When the interval of the markings is close to the resolving power of the lens in use and ordinary methods of illumination are used, dull images result, since only a part of the light entering the lens enters into the actual formation of the image of the structure, and the remainder exerts an obscuring effect, causing a lack of clearness or often a total obliveration of the structure.

OBJECT

It is the purpose of this paper to present a method of illumination control by which this excess light may be removed, allowing images of maximum clearness to be formed of this difficult type of structure.

METHOD OF PRESENTATION

For the purpose of illustrating this method I have

selected the test diatom Amphipleura pellucida, and shall describe the technique of its resolution in detail, explaining the main optical principles involved in each step. This object was selected because of its difficulty of resolution, and because it is well known to microscopists and physicists interested in the resolution of minute structure.

The same general method would of course be applicable in resolving any other object presenting structure of similar type.

DESCRIPTION OF THE DIATOM SELECTED.

Amphipleura pellucida * is a tiny, free swimming, single-celled plant, belonging to the family Naviculae

---

* Smith, Conspectus of Families and Genera of the Diatomaceae; The Lens, Jan. 1872, pp.1.

Van Heurck, Synopsis des Diatomees de Belgique; pp.113.

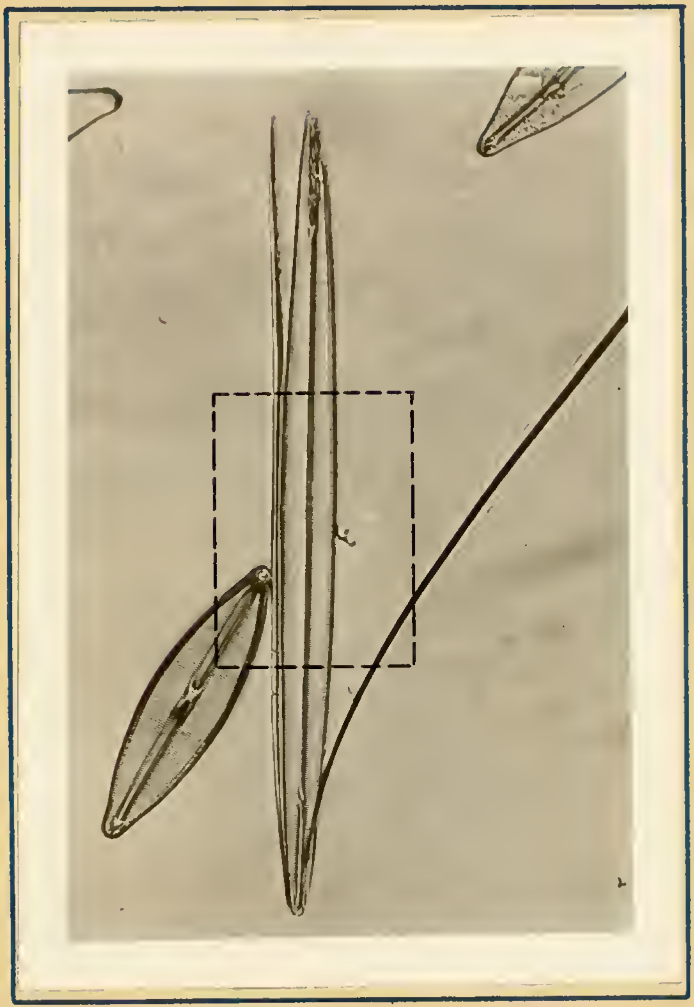
Van Heurck, Baxter translation; The Microscope, pp.63.

Spitta, Microscopy, 1920 ed. pp. 378, 402, Plate 6.

Boyer, Diatomaceae of Philadelphia and Vicinity, pp.78.

Wolle, Diatomaceae of North America, Plate 31.

Hind and Randles, Handbook of Photomicrography, pp.177.



GENERAL VIEW OF THE DIATOM
AMPHIPLEURA PELLUCIDA. ×920.

Part within dotted lines shown in Plates III, VI and VIII.

PLATE I.

of the natural order Diatomaceae. It is found in many fresh water rivers and lakes in various parts of the world. The valves or faces of the frustule, or box-like sileceous skeleton of the plant, are lanceolate in shape with a median longitudinal line terminated by two nodules as shown in Plate I.

Specimens from different localities vary somewhat in size, the one shown in the accompanying photographs from Moissac, France, measures 0.00408 inches in length and 0.00029 inches in width at the center.

When properly illuminated, a high apertured objective shows the surfaces of the valves apparently covered with rows of minute dots. In the photograph, Plate VIII, the transverse rows of dots are at intervals of 0.2645 microns and the longitudinal rows at intervals of 0.2158 microns, or 96,200 and 117,700 to the inch respectively. With ordinary methods of illumination this resolution into "dots" has long been considered one of the most difficult problems of the microscopist.

Concerning the true nature of this minute structure expert microscopists are not agreed, the best lenses at present available forming images which resemble the true

structure in general arrangement only,Plate XI, Fig.5. No attempt will be made to discuss the ultimate structure of the diatom.

OPTICAL SYSTEM

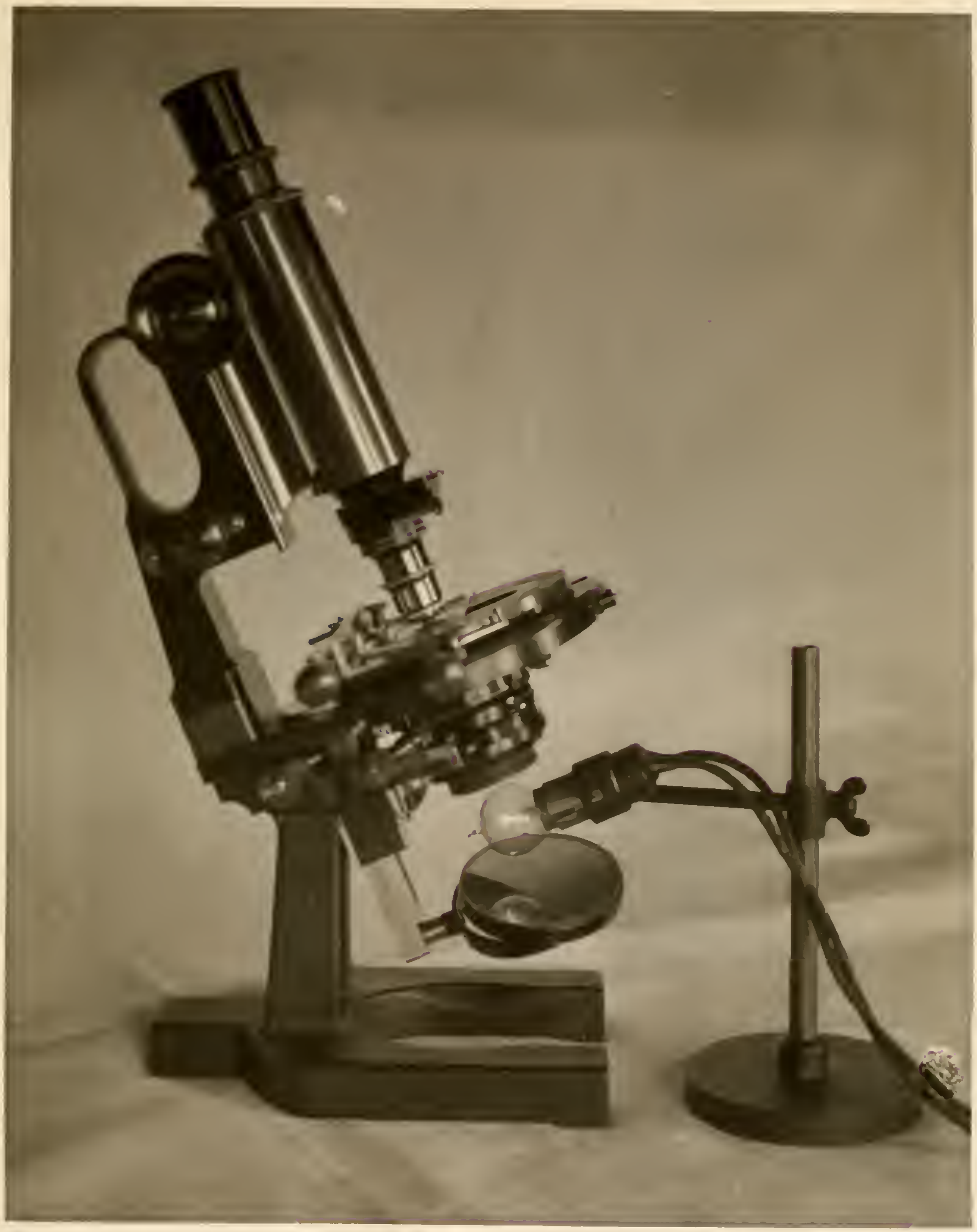
The objective employed for this resolution should be of the immersion type with a Numerical Aperture of at least 1.25, used in the conjunction with an eyepiece giving a final magnification of about 1500 diameters. An apochromatic objective and a compensating eyepiece is recommended.* The condenser when immersed must have an aperture sufficient to allow the back lens of the objective to be entirely filled with light. An excellent combination for this work is shown on Plate V.

LAMP

A small concentrated source of light which may be easily controlled is required. Very good results may be obtained with one of the low voltage gas-filled lamps of about twelve candle-power, commonly used in automobile lighting equipment. A small adjustable stand similar to the one shown in Plate II should be provided so that the lamp may be placed in any position. Current for this

---

* Etude sur les objectifs apochromatiquesAnnuaire de la Société Belge de Microscopie Vol. 23, pg. 41, 1899.



APPARATUS ARRANGED FOR VISUAL WORK.

PLATE II.

lamp may be obtained from a small transformer, through a resistance, or directly from a battery.

LIGHT FILTER

It is often desirable to place a light filter of glass or stained gelatine in the diaphragm carrier below the condenser. If an apochromatic objective is being used, a filter passing only blue or bluish-green light should be used since the resolving power of an objective is greatest when light of as short a wave length as is easily visible is used. Achromatic objectives however are usually corrected for green light only and the clearest images are formed by them when a filter passing only green light is used.*

MOUNT

A slide in which the diatoms are mounted in realgar (As_2S_2)** with a refractive index of 2.4 is prefered since the markings are more easily visible in a medium of high refractive index.***

---

* Spitta, Microscopy, 1920 edition, pg. 493.

** Van Heurck, Baxter translation, The Microscope, pg.305

*** The same, pg. 304.

SETTING UP APPARATUS.

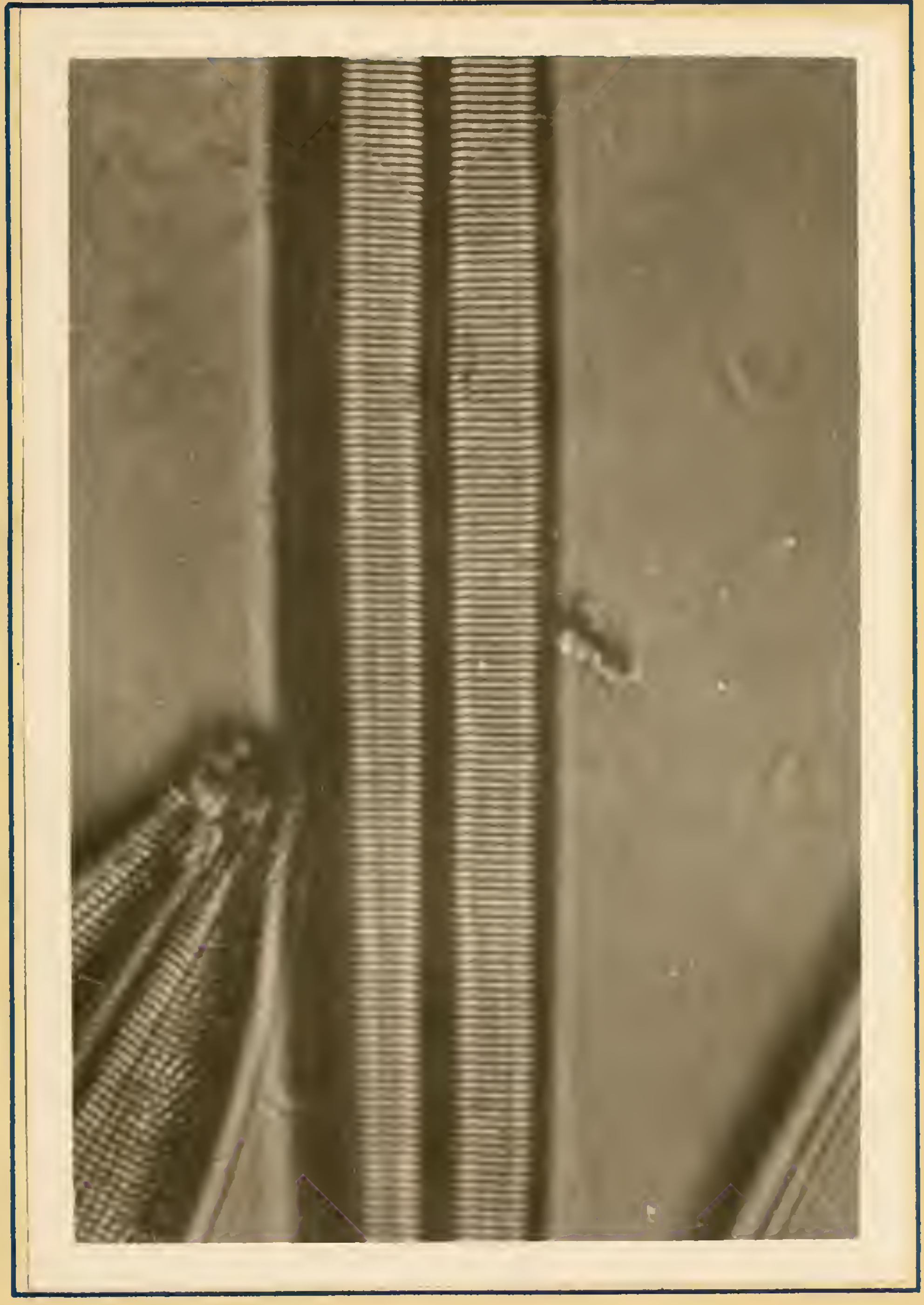
The slide should be oiled to both the condenser and the objective, forming complete homogeneous immersion, and the lamp placed between the mirror of the microscope and the condenser as shown in Plate II.

The slide should then be searched and a specimen selected for observation. One which has been split or broken is usually the most easily resolved. For convenience of description, the slide should be placed so that the long axis of the diatom selected lies from the top to the bottom of the field when the microscope is inclined, as shown in plate I.

IMAGE WITH NARROW CENTRAL BEAM.

The diatom should be illuminated first by a narrow central beam, which will be indicated by a small bright area at the center of the back lens of the objective. This bright area is an image of the light source formed by the objective near the upper surface of the back lens and may be examined by removing the eyepiece and looking into the tube.

When the eyepiece is replaced and the objective carefully focused, the surface of the diatom will appear to be without structure. This is because the central beam merely passes through the diatom and is not capable in itself of forming an image showing surface structure, Plate XI, fig.2.



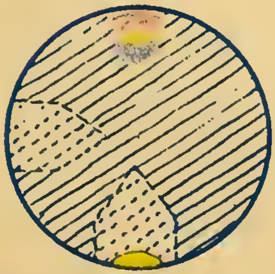


Fig. 3.- Appearance at back lens of objective.

AMPHIPLEURA PELLUCIDA ×4350.
Transverse striae shown by a beam of oblique polarized light along its axis.

PLATE III.

It should be carefully noted that the microscope objective is forming an image of an object not luminous in itself, but which merely transmits light from a relatively distant source. The optical principles involved then are entirely different from those employed by a camera or telescope lens, which form images of objects which may be considered as self luminous. For an elaborate discussion of the above, standard optical works should be consulted which discuss the "Abbe Theory of Microscope Vision".*

IMAGE SHOWING TRANSVERSE STRIAE.

The eyepiece should then be removed and the lamp adjusted so that the bright image in the center of the back lens of the objective is moved toward the observer until it is close to the bottom of the glass, as shown in Plate III, fig. 3.

When this has been done another image of the light source, fainter than the first and fringed with color, will be noticed near the top of the glass. This image is

---

* Van Heurck, Baxter translation, The Microscope, pp.21,32.

Carpenter, The Microscope and its Revelations, 1891 edition, pg. 36.

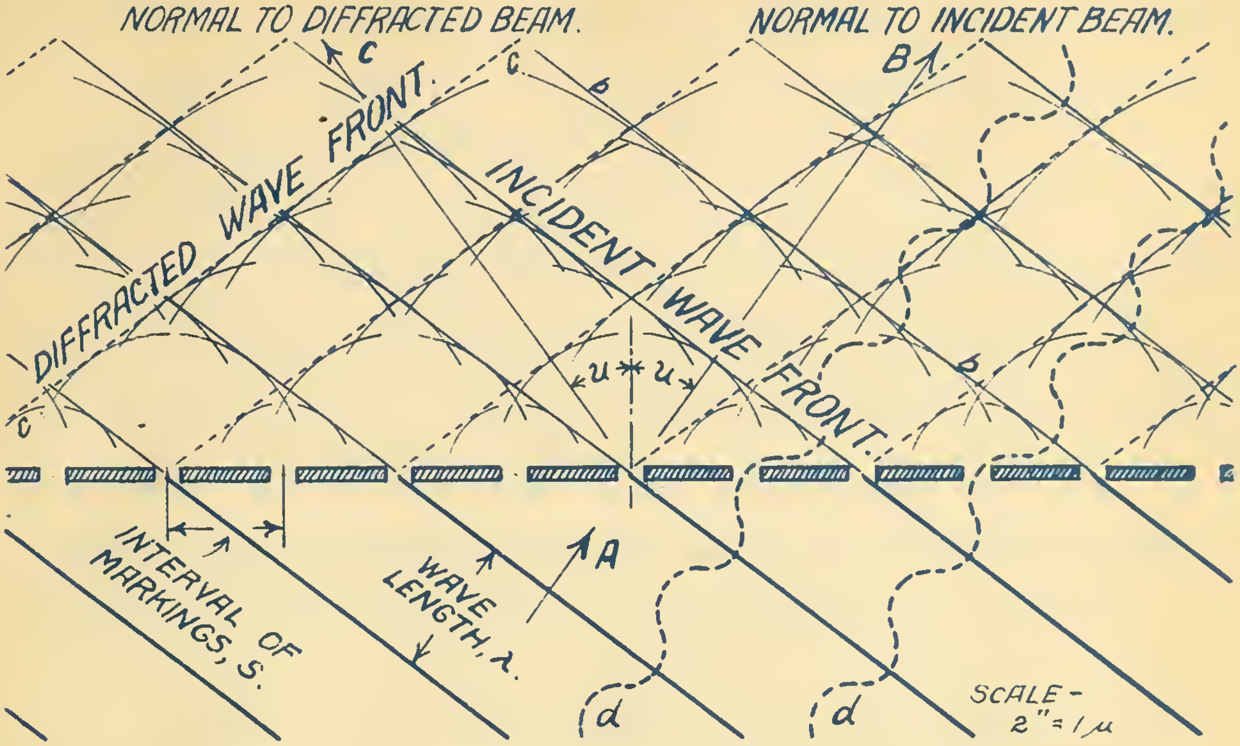
Encyclopedia Brittanica, 1911, Vol. 18, pg. 397.

Czapski, Der Theorie der Optischen Instrumente nach Abbe, 1893 edition, pg. 212.

λ (F line) in medium of 1.51 refractive index = 0.32 μ.

s-transverse lines = 0.265 μ. s-longitudinal lines = 0.216 μ.

$u = \sin^{-1}\frac{\lambda}{2s}$. u-transverse lines = 37°-27'. u-longitudinal lines = 48°-12'.



FORMATION OF INCIDENT AND FIRST DIFFRACTED BEAM BY STRUCTURE OF AMPHIPLEURA PELLUCIDA.

Light vibrating perpendicularly to the paper, advancing in the direction A, strikes a plate with periodic openings. Each opening becomes a separate source of disturbance and tends to send out a train of circular waves. These secondary waves interfere and produce two sets of plane waves b·b and c·c advancing in the directions B and C. Light components d·d vibrating in the plane of the paper are not subject to interference effects after passing the openings. and therefore contribute nothing to the diffracted beam C.

PLATE IV.

known as a diffraction spectrum and indicates the presence of a diffracted beam of light emerging from the objective.

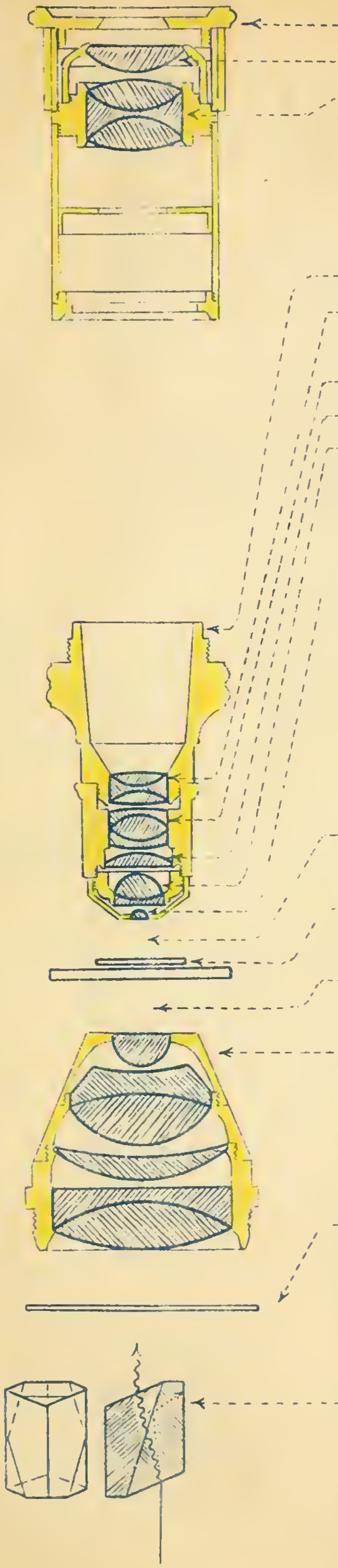
This diffracted beam is formed from the incident beam by the spreading action of the markings of the diatom which act as a transparent diffraction grating, graphically shown on Plate IV, and is found to be polarized, vibrating only in a plane parallel to the rows of markings causing the diffraction.

It is the interference of this diffracted beam with that part of the incident beam vibrating in this same plane which forms an image of the markings near the eyepiece diaphragm.

When the eyepiece is now replaced, careful focusing will show the surface of the diatom apparently covered with transverse striae as shown in Plate III. No image showing striae will be formed however unless both the incident and the diffracted beams emerge from the objective at the same time. *

---

* Carpenter, The Microscope and its Revelations, 1891 edition, pg. 59.



ZEISS #12 COMPENSATING OCULAR.
Produces the final magnification.
Corrects the chromatic difference of magnification left outstanding by the objective by causing the red image to be larger than the blue.

ZEISS 3 MM. APOCHROMAT N.A.-1.40.
Unites rays of three colors, practically destroying the secondary spectrum.
Corrects spherical abberation for two colors.
Completes the magnification of the objective.
Reduces the aperture to N.A. 0.29 and intentionaly introduces chromatic and spherical aberations to be better corrected by the two combinations above.
Reduces the aperture from N.A.-1.40 to N.A. 0.65. Being uncorrected, causes the formation of a larger blue than red image which error is allowed to remain outstanding in the objective, but is corrected by the "compensating" ocular.

IMMERSION OIL, $n = 1.515$.

REALGAR MOUNT OF AMPHIPLEURA PELLUCIDA.

IMMERSION OIL, $n = 1.515$.

LEITZ APLANATIC AND ACHROMATIC CONDENSER NA.-1.40.
Computed on lines analagous to an oil immersion objective.

WRATTEN "H" FILTER.
Passes light from 0.41 μ to 0.52 μ wave lengths with maximum transmission at about 0.47 μ.

TWO POLARIZING PRISMS.
Set at right angles to each other.

OPTICAL SYSTEM USED WHEN PRODUCING PLATES I, III, VI & VIII.

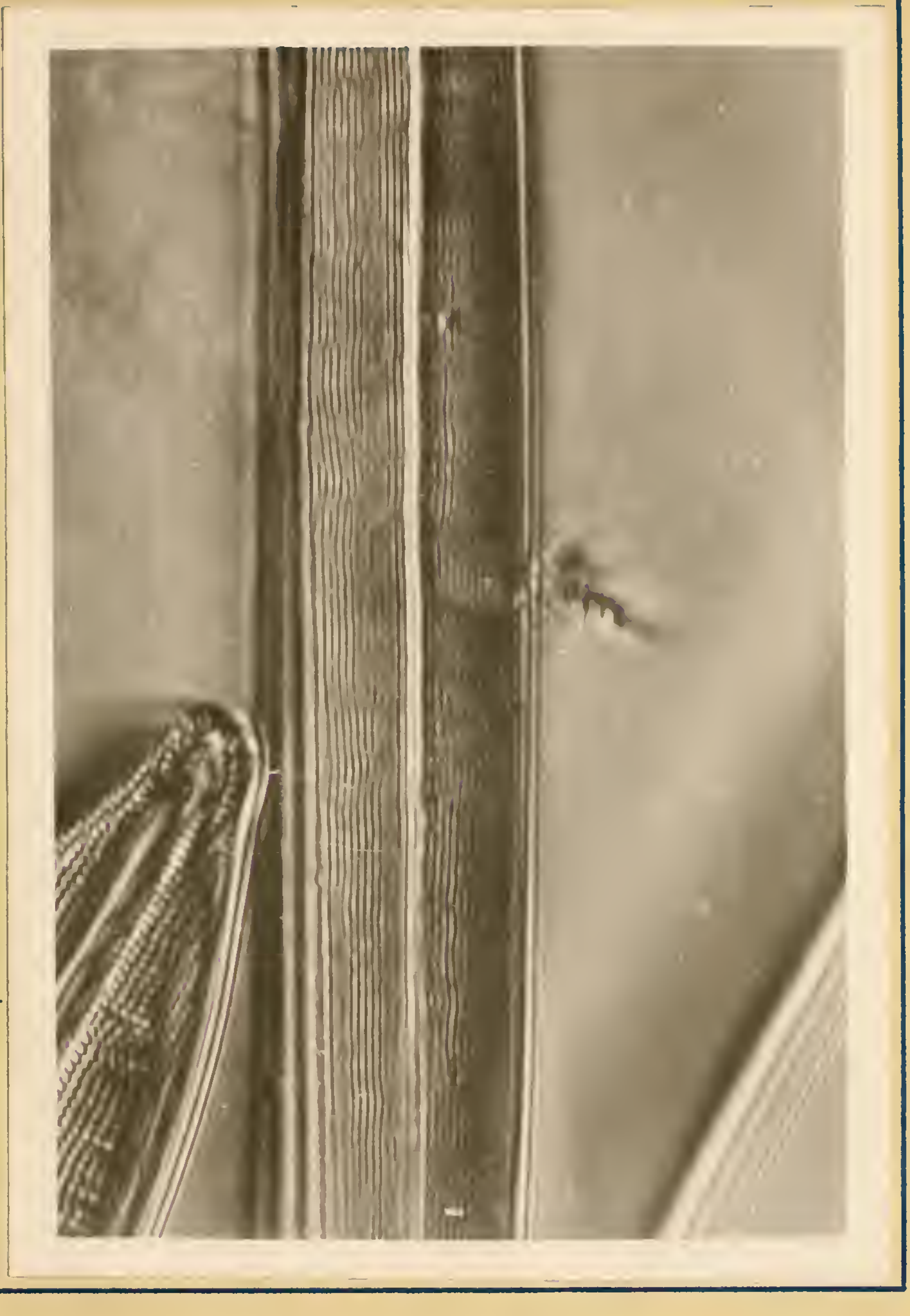
PLATE V.

SUPPLEMENTARY MICROSCOPE FOR ADJUSTING ILLUMINATION.

It may be desirable at times to enlarge these images of the light source with a supplementary microscope made by removing the draw tube, attaching a low power objective to the bottom, and placing a low power eyepiece in its regular position at the top. The small compound microscope so formed should then be replaced in the body tube and focused by sliding the whole in the draw tube mounting until an enlarged image of the light source images is obtained. The enlarged image so obtained permits the adjustment of the illumination to be very carefully made.

IMPROVEMENT OF IMAGE BY POLARIZING INCIDENT BEAM.

A prism from either polarizer or analyzer of a polariscope set, preferably removed from its mount, should then be placed in the path of the illuminating beam between the lamp and the condenser. When turned in a position so that the incident beam will be vibrating only in a plane parallel to the transverse striae, the image of these striae will appear much sharper and clearer than before. This is because the polarizing prism has deflected all of the excess light not actually entering into the formation of the image of the markings, which light, if not removed, naturally exerts



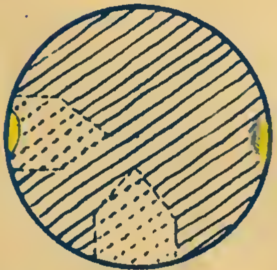


Fig. 6.-Appearance at back lens of objective.

AMPHIPLEURA PELLUCIDA ×4350.
Longitudinal striae shown by a beam of oblique polarized light across the axis.

PLATE VI.

an obscuring effect upon the image. *

IMAGE SHOWING LONGITUDINAL STRIAE.

When the transverse striae are clearly shown, the eyepiece should be removed, and without disturbing the prism, the lamp should be readjusted so that the main beam emerges from the extreme left of the back lens of the objective, as shown in Plate VI, fig.6. A diffraction spectrum will now be noticed at the right hand edge of the lens, but since the longitudinal rows of markings forming this diffracted beam are closer together than the transverse rows, this spectrum will be separated further from the main beam than the one produced before by the transverse rows.

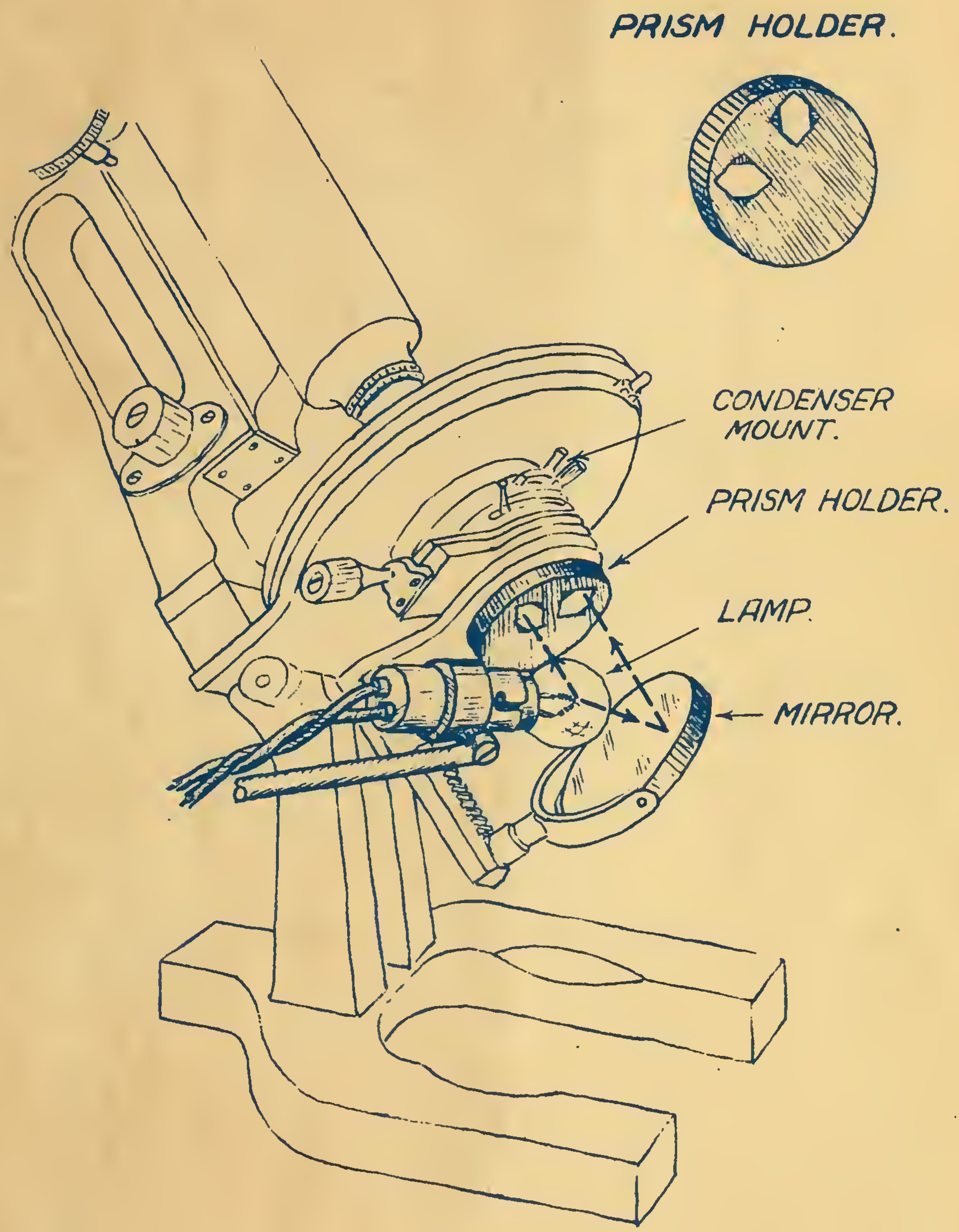
Without disturbing the position of the first prism, another polarizing prism should then be placed in the illuminating beam just below the condenser and turned so that the emerging light will be vibrating only in a plane parallel to the axis of the diatom. The proper appearance at the back lens with the apparatus set as described is

---

* Carpenter, The Microscope and its Revelations, 1891 edition, pg.315.

Journal Royal Microscopical Society, 1905, pg. 552.

Spitta, Microscopy, 1920 edition, pg. 499.



ARRANGEMENT OF ILLUMINATING APPARATUS TO PRODUCE TWO BEAMS OF OBLIQUE LIGHT POLARIZED AT 90° TO EACH OTHER.

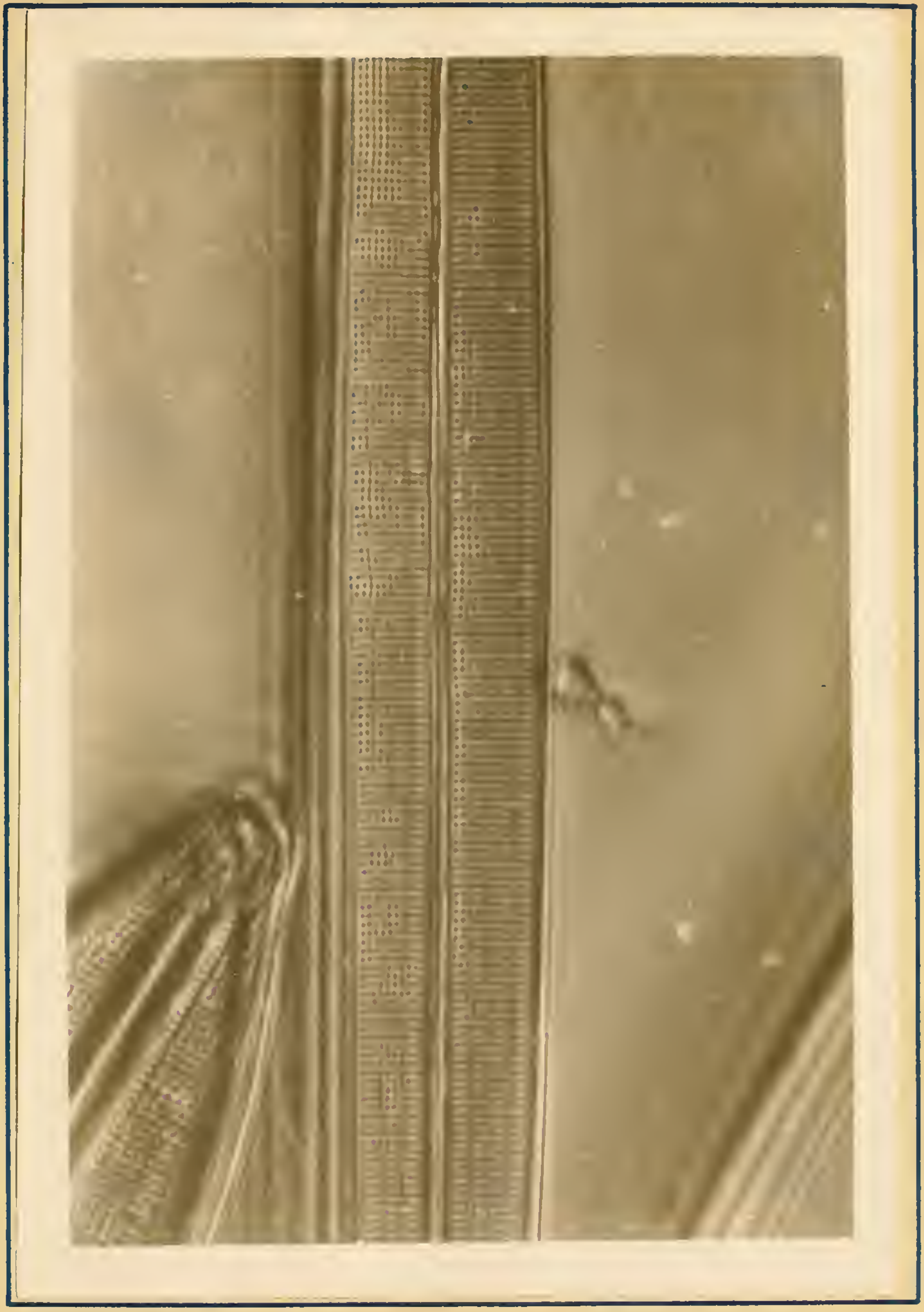
PLATE VII.

shown in Plate VI, fig. 6 .

When the eyepiece is now replaced, the surface of the diatom should appear to be covered with longitudinal striae as shown in plate VI. It may be well to note that if the illumination is not properly adjusted, an image showing a series of diffraction lines parallel to the edge of the diatom is often formed. These lines may easily be mistaken for the true lines which are parallel to the midrib and are undulating throughout their length. If this false image is obtained, the eyepiece should be removed and the lamp readjusted so that a diffraction spectrum is clearly visible at the extreme right of the back lens of the objective. The main beam should of course still emerge from the left edge of the lens. When the eyepiece is then replaced the image showing true longitudinal lines may be seen.

PRISM HOLDER.

A convenient holder for the two prisms is shown in Plate VII. It is made from a cylindrical piece of cork in which two holes have been cut just large enough to hold the prisms snugly. These openings are on the circumference of a circle the diameter of which is equal to the effective diameter of the condenser, their centers being located a



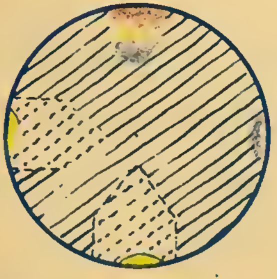


Fig. 8.-Appearance at back lens of objective.

AMPHIPLEURA PELLUCIDA ×4350.
"Dots" shown by two beams of oblique light polarized at 90° to each other.

PLATE VIII.

quarter of this circumference from each other. The whole may be held in the diaphragm carrier below the condenser.

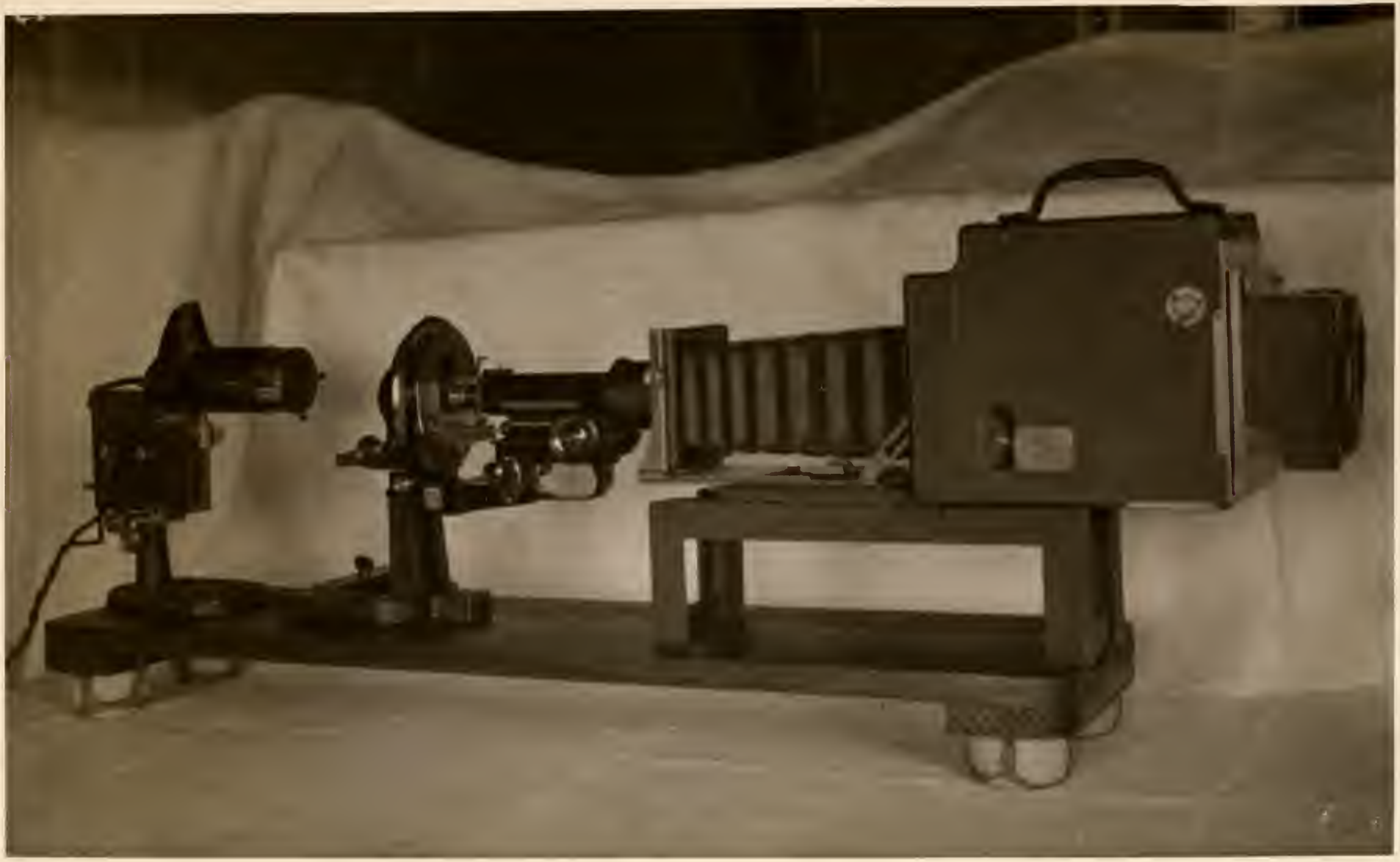
UTILIZING TWO BEAMS FROM ONE LIGHT SOURCE.

Now without disturbing the arrangement of the lamp or the prisms, the mirror should be shifted until a beam from the same lamp is reflected from the mirror into the prism first placed, as is clearly shown in Plate VII, and which will emerge from the bottom edge of the back lens.

IMAGE SHOWING STRUCTURE RESOLVED INTO "DOTS".

The proper appearance of the back lens at this time is shown in Plate VIII, fig. 8. The reflected beam with its accompanying diffracted beam will form an image showing transverse striae, which will blend with the image already formed showing longitudinal striae. However the image showing transverse striae probably will be brighter than the other.

The eyepiece should then be replaced and the mirror shifted slightly until the intensities of the two beams are balanced so that the resulting image shows the surface of the diatom covered with clearly defined dots as shown in Plate VIII. A little practice may be required



APPARATUS ARRANGED FOR PHOTOGRAPHIC WORK.

PLATE IX.

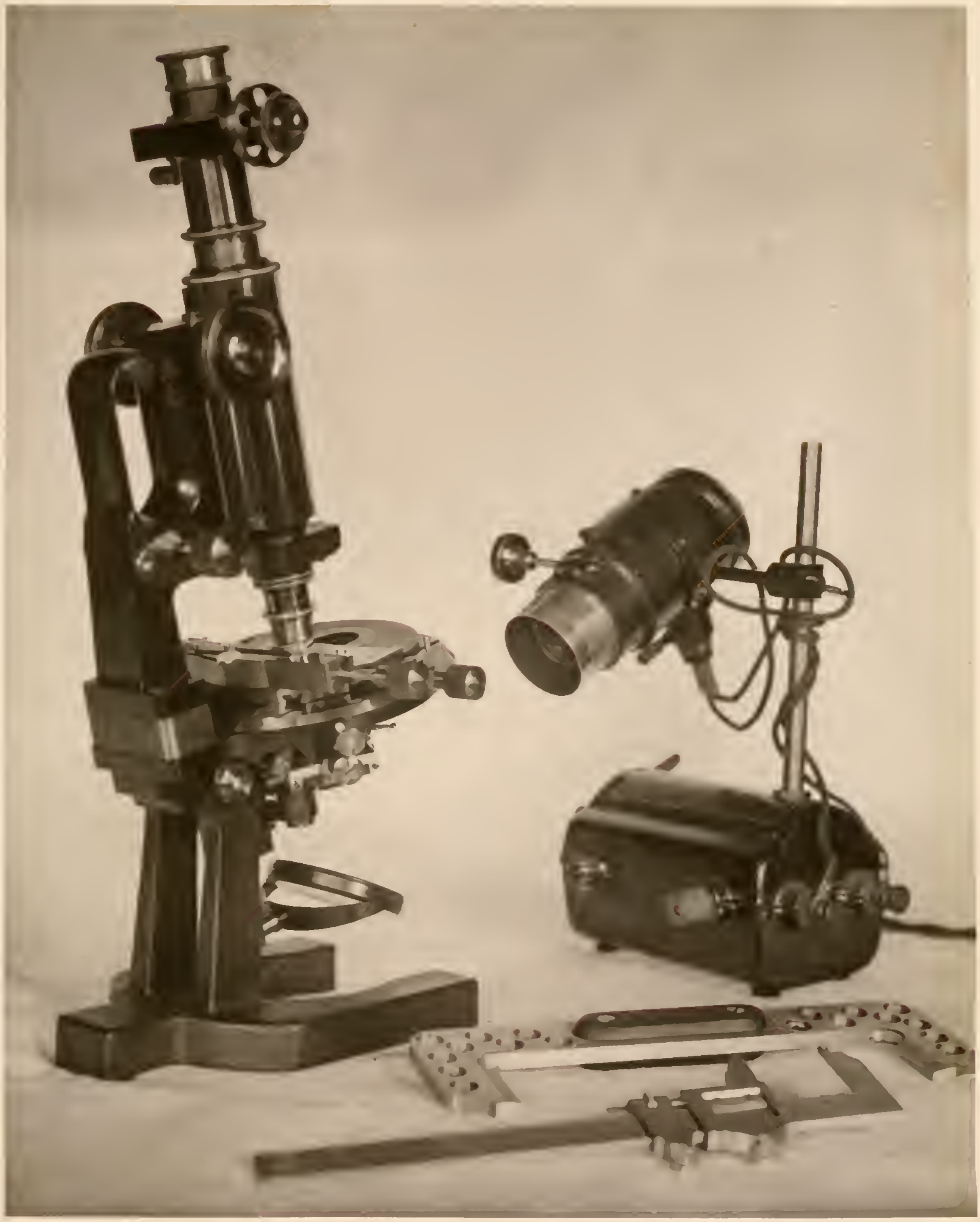
to effect this balance of intensity, but if a sharp clear image showing longitudinal lines is formed at first, a good image showing dots should be readily obtained, its perfection depending upon the quality of the objective employed.

OTHER METHODS OF OBTAINING SEPARATE BEAMS.

The method just described of placing the lamp between the condenser and the mirror furnishes sufficient light for both visual and photographic work, and the ease and rapidity with which the illumination may be adjusted is very desirable in this class of work.

However, rather long exposures are required when photographing the markings of the diatom, and while less convenient to manipulate, exposures may be shortened by directing a single parallel beam from a powerful light source through both of the prisms and balancing the two images by means of suitable diaphragms placed either between the lamp and the prisms or between the prisms and the condenser.

Another method is to use two separate light sources, projecting one beam directly through one Nicol prism and reflecting the other beam from a small reflecting prism or mirror through the other Nicol prism. This latter



APPARATUS ARRANGED FOR LINEAR MEASUREMENT.

PLATE X.

method while requiring more apparatus than the other is convenient to manipulate and is recommended where short exposures are desired.

Regardless of the arrangement of the light source the polarizing prisms should best remain in the same position as before and the appearance at back lens of the objective should of course remain the same.

ADVANTAGES OF THE DESCRIBED METHOD OF ILLUMINATION.

The method which is commonly used to resolve structure of this type * is to adjust the illumination so that one incident beam and two diffracted beams at approximately right angles to each other emerge from the objective at the same time as shown in Plate XI, fig. 5. With this method however, not all of the light of the incident beam enters into the actual formation of the image, and an obscuring effect on the image will always be present due to this excess light. When several orders of spectra are present this effect is not noticeable, but as the intervals the structure approach the resolving power of the lens in use, this obscuring effect becomes more and more pronounced.

---

* Spitta, Microscopy, 1920 edition, pg. 198.
Hind and Randles, Handbook of Photomicrography, pg. 177.

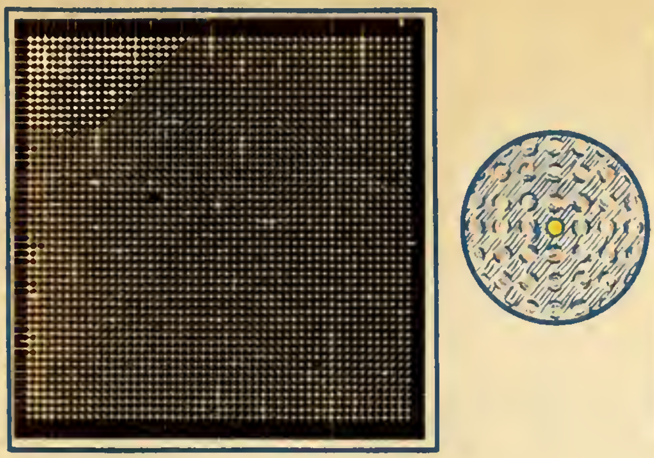


Fig. 1-Appearance with lens of sufficient aperture to pass three orders of spectra. This appearance closely resembles the true structure.

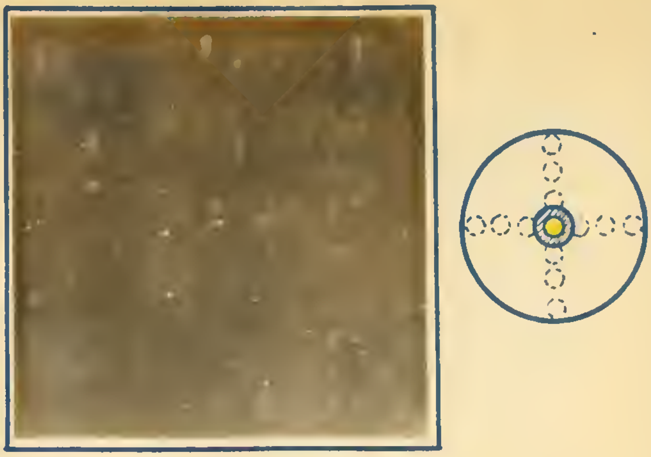
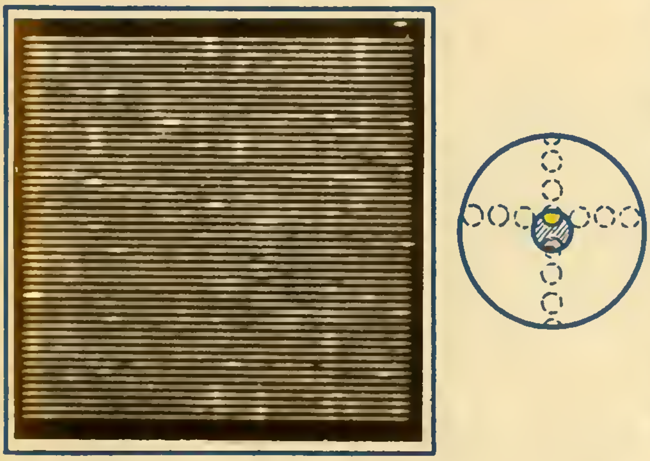


Fig. 2-Appearance when aperture is reduced by means of a diaphragm above back lens so that the central beam only is allowed to emerge.



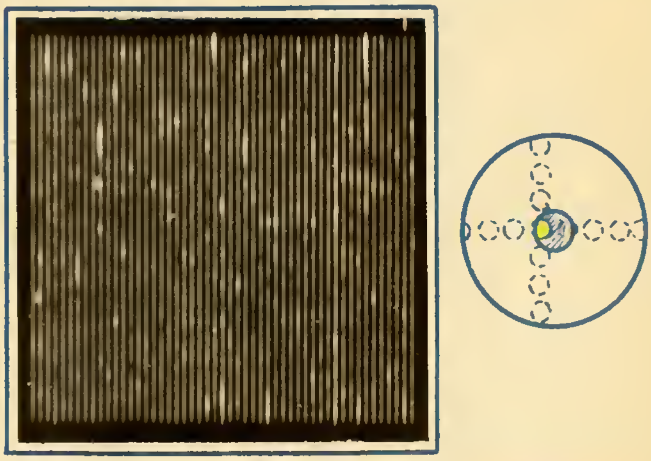


Fig. 3-

Fig. 4-Appearances with reduced aperture when the illumination is adjusted so that the central beam and a single diffracted beam emerge from the objective.

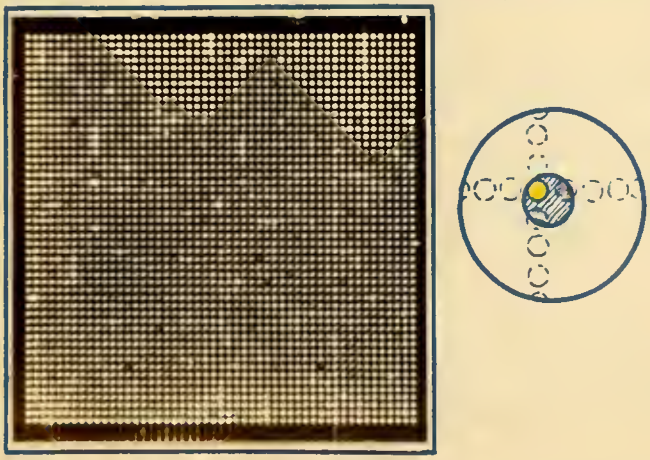
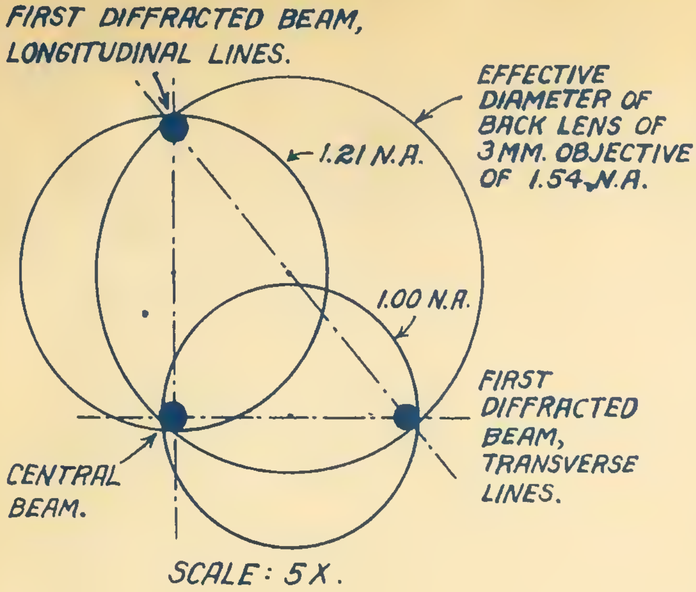


Fig. 5-Appearance with reduced aperture when the illumination is adjusted so that two diffraction beams emerge with the central beam. This image is formed by the blending of the two separately formed images shown in figs. 3 and 4 and will be seen to resemble the true structure in general arrangement only.

APPEARANCES OF ABBE DIFFRACTION PLATE

UNDER DIFFERENT METHODS OF ILLUMINATION. X90.

PLATE XI.


FIRST DIFFRACTED BEAM, LONGITUDINAL LINES.
EFFECTIVE DIAMETER OF BACK LENS OF 3MM. OBJECTIVE OF 1.54 N.A.
1.21 N.A.
1.00 N.A.
FIRST DIFFRACTED BEAM, TRANSVERSE LINES.
CENTRAL BEAM.
SCALE: 5X.

Intervals of markings of specimen of Amphipleura pellucida shown on Plate VIII,
s-(transverse) $= 0.265\,\mu$.
s'-(longitudinal) $= 0.216\,\mu$.

Assuming a wave length in air $\lambda = 0.486\,\mu$ (F line).
λ' in medium of 1.51 refractive index $= 0.322\,\mu$.

Half angle between incident and first diffracted beam,
$u = \sin^{-1} \lambda'/2s$.
u (transverse) $= 37°\text{-}27'$.
u' (longitudinal) $= 48°\text{-}12'$.

Linear distance of center of incident beam from center of first diffraction image at upper focal plane of 3mm. objective,
$d = n \sin u \times 2f$ where f = focal length of objective.
d (transverse) $= 1.51 \times \sin 37°\text{-}27' \times 2 \times 3 = 5.51$ mm.
d' (longitudinal) $= 1.51 \times \sin 48°\text{-}12' \times 2 \times 3 = 6.75$ mm.
d'' (dots) $= \sqrt{5.51^2 + 6.63^2} = 8.71$ mm.

Assuming a beam 0.5mm in diameter necessary to furnish sufficient light for distinct vision, the necessary diameters of the back lens of a 3mm objective for resolution are,
D (transverse) $= 5.51 + 0.50 = 6.01$ mm.
D' (longitudinal) $= 6.75 + 0.50 = 7.25$ mm.
D'' (dots) $= 8.71 + 0.50 = 9.21$ mm.

Equivalent Numerical Apertures necessary for resolution with a single beam, $N.A. = D/2f$.
N.A.-(transverse) $= 6.01/6 = 1.00$.
N.A.'-(longitudinal) $= 7.25/6 = 1.21$.
N.A.''-(dots) $= 9.21/6 = 1.54$.

It is therefore evident that with apparatus ordinarily available the visual resolution into "dots" must be made with two separate beams or two separate portions of one broad beam.

THEORETICAL APERTURES REQUIRED FOR RESOLUTION OF AMPHIPLEURA PELLUCIDA.

PLATE XII.

The described method of removing this excess light by permitting two beams to be separately polarized, allows images of maximum clearness to be formed.

This method has the further advantage of permitting the full aperture of the objective to be used in the formation of each separate image, allowing the resolution to be made with an objective of lower Numerical Aperture than would ordinarily be required.

Respectfully submitted to the
President and Faculty.

Dan M Stump.

May 1, 1921.

Dan M. Stump.